APPENDIX 15.D — WETLAND CREATION AND RESTORATION BANK

15.D.1 INTRODUCTION

Wetland creation and restoration is a relatively new field brought about by the USACE's Section 404 permit regulations and various State laws. This Appendix and the complementary Appendix 7.D in Chapter 7 is presented to give the highway hydraulics engineer some familiarity and guidance with the subject. Because this is basically a "how-to manual," it is not intended to be a definitive thesis on wetlands hydrology. For a more complete discussion of the subject, the reader is referred to Reference *(18)*, Section 15.G.15. Although wetland hydrology is not their primary responsibility, highway hydraulics engineers may be required to work in this area on an increasing frequency as wetland mitigation needs increase in highway construction. Their responsibility will be to fill the role of the hydrologist in the wetland restoration/creation process. Because highway hydraulics engineers are usually concerned with providing for the hydrologic and hydraulic design needs for a highway construction site, they must become knowledgeable in the biological aspects of wetland restoration/creation to successfully fulfill their role in the process. The information supplied in this Appendix is designed to provide a background understanding of the process in wetland restoration/creation and the associated biology and terminology. The hydrologic and hydraulic design procedures are presented in Chapter 7, Appendix 7.D.

Groundwater is often an important aspect of wetland creation/restoration projects. Most highway hydraulics engineers are surface water specialists and do not have extensive experience in groundwater. This document is primarily concerned with the surface water aspects of wetland restoration/creation and discusses the groundwater aspects only as necessary. If groundwater is important to a project, it is recommended that a person, qualified in that area, be engaged to handle that aspect of the project.

The lead role in creation/restoration projects is often taken by a wetland specialist, usually a biologist. However, the hydrologist/geohydrologist has one of the most important responsibilities in the restoration/creation process. This responsibility is to assure that the proper hydrology is supplied to the project. "*Hydrology is the most important variable in wetland design. If the proper hydrologic conditions are developed, the chemical and biological conditions will respond accordingly.*" (Reference *(15),* page 592). The ultimate success of any wetland project depends on establishing or restoring and maintaining the appropriate hydrology to support the wetland. Without the proper hydrology, the wetland project will fail. It should be noted that hydrology is not the only important variable in the wetland creation/restoration process. Wetlands are, by definition, vegetated areas that use water at a high consumption rate. All the variables necessary for vegetation must be present. Another major variable is the soil substrate. It must be present to supply the necessary nutrients and rooting medium.

Wetland hydrology may be roughly defined as the flow of water into, through and out of a wetland and the characteristics of this flow. The characteristics include the depth, duration, velocity, sediment load, chemistry and temperature.

The sensitivity of wetlands to hydrology is seen in the water depth tolerance for wetland vegetation. For some species, the range of depth tolerance is in the order of 1 in to 4 in. A small change in hydrologic conditions will result in a major change in the species richness, diversity and abundance of the biota. An abrupt and major change in the living matter in a wetland can result from a relatively minor change in hydrology. Therefore, the hydrology of a proposed wetland restoration or creation site must be thoroughly evaluated and very carefully designed.

The hydrology determines the availability of water and the depth, velocity, chemistry and soil conditions including the degree of substrate anoxia. The water inflow into wetlands is the main source of nutrients for the wetland fauna and flora, and the outflow often removes biota and non-biological material from the wetlands. "*In the short-term, hydrology determines vegetation, fauna and most of the wetland functions. In the longer term, hydrology determines, through erosion and deposition, the shape, size, depth and even the location of a wetland. This, in turn, determines vegetation, fauna and wetland functions.*" (Reference *(11)*, page 4). Hydrology controls the types of plants that grow in an area. Fewer and fewer types of plants out of thousands can grow as saturation conditions increase. Although the variety of plants that can grow in a wetland decreases as the depth and duration of flooding increases, the wetland's overall production of biota may not necessarily follow this trend. Though diversity may decrease, the total volume of plants and organisms supported by the wetland may, in some cases, be greater for the deeper, more frequently flooded areas.

Hydrology directly influences productivity by controlling nutrient cycling and availability, import and export of nutrients and fixed energy supplies in the form of organic particulates and decomposition rates. Under prolonged inundation, many important nutrients are immobilized under reducing conditions in the substrate and unavailable to plants and separated from the water column. Periodic drying and oxidation returns these substances to active portions of the cycles within the water column and near the surface of the substrate, resulting in an explosive growth response by plants and animals. Changes in oxygen availability and concentrations caused by inundation also strongly influence decomposition rates because anaerobic rates are generally only 10% of aerobic decomposition rates. Low decomposition rates in anaerobic environments is the principal reason why many wetlands accumulate substantial quantities of partially decomposed organic material (Reference *(7)*, page 23).

Practical experience and the available science on wetland restoration and creation are limited for most types and vary regionally. There have been hundreds if not thousands of projects completed along the eastern Atlantic Coast but fewer along the Gulf and Pacific Coasts. There has been a fair amount of monitoring and follow up on these projects (Reference *(13)*, Section 15.G.15.). Much less is known about inland wetland creation and restoration. Two types of wetland projects have been fairly common. These are impoundments for waterfowl and wildlife and creation of wetlands on dredged spoil areas by the USACE. Although a lot of material has been published on waterfowl habitat enhancement, only a moderate portion of the literature addresses the wetland issues critically. The most is known about the USACE research on streamside wetlands created on dredged materials.

The understanding of the role hydrology plays in the wetland environment has not been fully developed. There has been insufficient research in this area. It is very difficult to quantify the various components in the water balance in a wetland. Hydrologic processes need to be carefully measured and monitored over a long period of time to develop a better understanding of the processes involved.

The role of long-term hydrologic events such as flooding and long-term fluctuation in the water level and their effects on plant life is not known. This is particularly true for the forested wetlands. It has not been determined how low-probability floods affect wetland forests. The hydrologic needs and requirements of various plants and animals including the seasonal variation in wet and dry periods need to be studied. In a recent study, there was some indication that variation in plant community may be explained by 1-day to 10-day duration flood frequencies. The 6-day duration flood frequency was recommended as a reasonable measure (Reference *(20)*, Section 15.G.15).

Most of the materials available on wetland hydrology have not been written by hydrologists, so that detailed design procedures are difficult to find. Those that are available do not always use terminology and notations in the manner familiar to highway hydraulics engineers. There is an urgent need for research to be done in the whole area of wetland hydrology and the hydrologic design for wetlands.

Some useful references for tidal and freshwater wetland creation and wetland hydrology that are not specifically cited within this Appendix are References *(1)* through *(5)*, *(10), (12)* and *(14)*.

15.D.2 WETLANDS AND WETLAND MITIGATION PROJECTS (Definitions)

The USACE (*Federal Register* 1982) and the US Environmental Protection Agency, USEPA, (Federal Register 1980) have defined "Jurisdictional" wetlands as: "*Those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs and similar areas*." (Reference *(19)*). Wetlands will have three general diagnostic environmental characteristics — vegetation, soils and hydrology:

- The prevalent vegetation consists of plants that are adapted to the conditions indicated above and have the ability to grow, reproduce and/or persist in anaerobic soil conditions.
- The soils are hydric or have characteristics of soils developed under reducing conditions.
- The hydrology is such that the area is permanently or periodically inundated up to 6.5 ft deep, or the soils are saturated to the surface sometime during the growing period of the predominant vegetation.
- Wetlands are an ecotone or transition zone between dry land and deep water (water 6.5 ft or more deep). This boundary shifts back and forth due to changing climatic conditions. Climatic conditions gradually change between wet and dry over long periods of time. This causes a gradual change in soil wetness affecting vegetation and blurring the wetland boundary. Only properly trained wetland specialists are qualified to identify wetlands.

Wetland mitigation projects involve creation or restoration of wetlands. Wetland creation projects are the creation of a wetland where none existed before. This type of project is difficult to construct and has less chances of success than a restoration project because it requires a successful change in hydrology. Restoration projects involve repairing and restoring a damaged or destroyed wetland. Success is more likely for this type of project.

15.D.3 WETLAND HYDROLOGIC PRINCIPLES

Wetland areas may experience periods of being wet and dry during the year. One wet period must be during the growing season of the vegetation. The wet period may involve inundation or soil saturation. It must persist for sufficient time to cause the vegetation to be predominantly hydrophytic. There can be some non-hydrophytic plants in a wetland but they will not be predominant.

The seasonal variation in wet and dry periods in a wetland is called hydroperiod. The hydroperiod is the result of the summation of all the inflows and outflows in a wetland. It is influenced by topography, geology, climate and the adjacent water bodies. The results are wet and dry periods that vary from year to year. It is this pattern that determines the characteristics of the wetland. The dry periods are called drawdown. The role of drawdown in plant zonation and succession is well understood. It is an important tool of wetland management and should be an important part of wetlands planning considerations. In wetland restoration projects, drawdown is enhanced by gently sloping bottoms. If drawdown is not planned for in wetland development, the result will likely be an open body of water rather than wetlands.

There may be some long-term cycles in the amount of water available for the wetlands. Prairie potholes have a wet and dry cycle that ranges from 10 to 20 years. Tidal wetlands will be affected by the 19-yr tidal cycle. The 19-yr tidal cycle is caused by the periodic variation in the moon's orbit around the earth.

In a simplified view of natural wetlands, the supply of water overwhelms the outflow capacity of the area. The resulting oversupply of water is stored and released slowly over time. If the water is released too quickly, a wetland will not form. The storage may be in the form of surface water impoundment or in an elevated groundwater table. In some cases, there may be no outflow from the wetlands such as prairie potholes. Some wetlands are formed when the watertable is at or near the surface.

The basic procedure to restore or create a wetland area in this simplified model is to construct the conditions that will provide the necessary excess water. There are several approaches to provide the excess water. One approach, particularly where the water supply is limited, is to create an impoundment. To do this, the soils must be impervious and some type of spillway control structure must be constructed. Sufficient control must be built into the spillway so that the appropriate wet and dry periods will result. The critical factor is a sufficient water supply to make the system work. Another approach is to have a sufficient supply of water to raise the groundwater table to the required levels to maintain a wetland area.

15.D.3.1 <u>The Water Budget</u>

The primary procedure that is used to determine the hydroperiod for a proposed wetland restoration/creation project is the development of a water budget. The water budget is a routing procedure that is developed on a monthly basis over a period of a year. It is the summation of the water inputs and outflows in a wetland area. Expressed in terms of depth of water in the wetland basin in feet, it measures the volume of water stored in the wetland. The inflows to the wetlands are precipitation, surface water flow and groundwater flow. The outflows are evaporation and transpiration (terms sometimes combined as evapotranspiration), surface flow and groundwater flow. One or more of the types of inflow or outflow may not be present in a particular wetland. A successful design can be accomplished if there is a reliable water source available. The source can be a permanent stream, the runoff from a large watershed, a spring or a well-understood groundwater table. To be assured that the proper water levels can be maintained under extreme conditions, a water budget should be developed for the project site for the wettest year of record, the driest year and a normal precipitation year. The purpose in evaluating these three conditions is to provide the wetland specialist with the range of hydrologic conditions that the wetland area will experience. This will allow the wetland specialist to evaluate the chances for success of the wetlands and to determine the need for adjustment in the design for the hydrology of the wetlands. The water budget process is explained in Chapter 7, Appendix 7.D.

15.D.3.2 Wetland Soils

One of the important aspects of wetlands is that the soils are hydric. Hydric soils are saturated long enough in the growing season to support wetlands or hydrophytic vegetation. The soils may be organic or mineral. *"Organic soils are commonly known as peat or muck. Organic soils (Histosols) develop under conditions of nearly continuous saturation and/or inundation. All organic soils are hydric soils, except Folists, which are freely drained soils occurring on dry slopes where excess litter accumulates over bedrock."* (Reference *(19)*). The mineral soils may range from sands to clays.

Hydric soils are anoxic, or they lack or have low levels of oxygen. The primary difference from non-hydric soils is that water fills the voids between soil particles, greatly inhibiting the replacement of atmospheric oxygen in the soil. As a result, there is only a thin layer 1 mm to 5 mm thick that has adequate oxygen to maintain aerobic/oxidation conditions. Almost everything below this layer is anaerobic. Shortly after the soil is flooded, the microbes will use up the available oxygen, and the soil will become anaerobic. Under anaerobic conditions, decomposition is greatly reduced. *"In summary, the loss of soil oxygen creates difficult environmental conditions for living organisms and unusual chemical conditions that, in turn, result in the unique attributes of wetland soils that contribute to their functional values."* (Reference *(7)*, page 33). For a more complete discussion of hydric soils, see Reference *(7)* and Reference *(19)*, Section 15.G.15.

Hydric soils occur when they have been subject to hundreds of years of reducing conditions from periodic saturation. Hydric soils from an impacted wetlands should be stockpiled or saved for placement into another wetland mitigation area. They should be placed in a created wetland before planting or flooding. Experience dictates that wetland creation is not successful without the placement of hydric soils.

15.D.3.3 The Functions of Wetlands

One of the important aspects of wetlands is the variety of functions that they perform. In the restoration/creation process, the determination of the functions that the proposed project is to fill is one of the most important design considerations. Natural wetlands perform a number of functions. Many functions are based on subtle relationships, which may have taken from as few as three years to thousands of years to develop. A restored wetland can, in many cases, perform most of the functions that it did in the pre-impact state. Created wetlands may be less successful in filling the functions of natural wetlands in the short term. In the long term, the wetland functions should be more established.

The ability to restore or create wetland functions is dependent on how much is known scientifically about the functions, the ease and cost of construction and the varying probability that construction can cause nature to duplicate certain functions. As examples:

- Flood storage is relatively easy to duplicate. It primarily depends on topography, which is easy to construct.
- Groundwater recharge and discharge functions are more difficult to assess and construct.

- Infiltration, which is necessary for groundwater recharge, is difficult to construct. Sandy soils may become impermeable over time due to deposits of organic material.

15.D.3.4 <u>Types of Wetland Functions</u>

Some of the major functions performed by wetlands are described below.

15.D.3.4.1 Plant and Animal Habitat

"Wetlands represent a very small fraction of our total land area, but they harbor an unusually large percentage of our wildlife. For example, 900 species of wildlife in the US require wetland habitats at some stage in their life cycle, with an even greater number using wetlands periodically. Representatives from almost all avian groups use wetlands to some extent and one third of North American bird species rely directly on wetlands for some resource.

Due to the diversity of habitats possible in these transition environments, the Nation's wetlands are estimated to contain 190 species of amphibians, 200 species of birds and over 5,000 species of plants. Many wetlands are identified as critical habitats under the provisions of the Endangered Species Act, with 26% of the plants and 45% of the animals listed as threatened or endangered either directly or indirectly dependent on wetlands for survival." (Reference *(7)*, pages 15 and 16).

15.D.3.4.2 Food Chain Support

Wetlands have the capacity to accumulate nutrients. These nutrients are then used by organisms as needed. In wetlands, food chains are very elaborate and diverse. Almost all fresh water species are dependent on wetlands at some time in their lives. Many salt-water species spawn offshore then migrate to the salt-water marshes for their juvenile stages.

15.D.3.4.3 Flood Storage

Many wetlands are natural flood detention areas. Wetlands affect flood flows in two ways. First, the thick vegetation retards the flow of water; second, they provide detention by storing floodwaters and slowly releasing them over a period of time. The flood storage effects have greater impacts if the wetland is located at the upper end of a drainage basin. It has been found that, where large areas of wetlands have been filled, flooding has greatly increased.

15.D.3.4.4 Sediment and Pollutant Trapping

Because of the slow water velocities in wetlands, most sediment flowing into the wetlands will be trapped. Similarly, some pollutants will be taken up by the vegetation or soils in the wetlands. Because of this trapping ability, wetlands are often created for use in treating wastewater. Although anaerobic and aerobic processes, certain kinds of chemicals are removed from the water.

In contrast, high sediment loads can have serious detrimental effects on wetland vegetation and wildlife. A moderate amount of sedimentation may enhance the wetland by bringing in nutrients. Excessive sedimentation may smother plants and change the elevation of the wetland. Changes in elevation due to sediment deposits will affect the extent and length of time of soil saturation that, in turn, will alter the success of wetland plant species in the area. Significant changes in elevation could reduce flood storage.

15.D.3.4.5 Shoreline Protection

Wetland vegetation along shorelines of lakes, rivers and coastlines provides soil stabilization by absorbing and dissipating the energy of waves, currents and tides and by binding the soil.

15.D.3.4.6 Groundwater Recharge

Groundwater recharge is often listed as one of the benefits in wetland restoration. However, on the whole, wetlands utilize much more groundwater than they contribute in recharging. Most wetlands receive continuous discharges from groundwater and act as a recharge area only during storm events. Most wetlands have limited value as groundwater recharge areas, because the accumulation of decaying organic matter and organic soils, which characterize hydric soils, have such low permeabilities. Where the soils have become less pervious because of this accumulation, most recharge will occur only around the edges of the wetlands in the upland areas. Wetlands that are formed by the ground line intersecting the watertable can serve as groundwater recharge, only if there is sufficient surface water or precipitation inflow into the wetlands and sufficient time for infiltration and deep percolation to occur. This rarely happens.

The possibility of contamination of the groundwater aquifer should be a consideration. If the wetlands could be contaminated by roadway spills or agricultural runoff, recharge of the watertable would not be desirable.

15.D.3.4.7 Groundwater Discharge

Wetlands that intersect the watertable can serve as groundwater discharge points if the piezometric surface (head) is sufficient. The variability in the level of the watertable is difficult to predict. Due to this uncertainty, when groundwater is being utilized as the primary source of water for a wetland restoration project, extra effort may be required to verify that sufficient water supplies are available to meet the needs of the proposed wetland.

15.D.3.4.8 Biogeochemical cycling

Wetlands accumulate and cycle various chemicals. Two examples of this process are the accumulation of various forms of carbon in peat bogs and the reaction of sulfur with other elements in wetlands and its release as gaseous and liquid compounds.

15.D.3.4.9 Recreation, Education, Heritage

Wetlands are used for hunting, fishing, birding and canoeing. The rich habitat of wetlands demonstrates the dynamics of ecological systems. Much of our early history has important ties to wetlands and swamps.

15.D.4 CRITICAL HYDROLOGIC VARIABLES OF WETLANDS

There are certain hydrologic variables that are critical for making management decisions for wetland projects. Some of these variables are directly related to hydrologic variables, and others interact with water to produce or affect certain wetland characteristics or functions.

15.D.4.1 Water Sources and Outflow from Wetlands

The source of water to wetlands will influence the characteristics of the wetlands. Streams or rivers supply water with relatively high energy and large sediment and nutrient loads. The high energy can damage some features of wetlands. Although the sediment can choke out or bury some vegetation and animal life, nutrients carried by the sediments can also enrich the wetlands. Sheet flow can also bring sediment, nutrients and pollutants to the wetlands. The sediment loads from sheet flow will be relatively minor compared to the loads from a river. The pollutants can be from agricultural runoff containing fertilizers, insecticides, herbicides and animal waste products. In addition, pollutants can come from urban and industrial runoff. Groundwater-supplied wetlands will have relatively clean and cool water. In tidal areas, salinity, basin flushing and wave energy can impact the wetlands. The salinity will control the type and characteristics of the wetlands.

The outflow from the wetlands affects the nutrient balance of wetlands. If the outflow is through a surface flow or a stream, some of the dissolved and suspended material will be transported out of the wetland. If the primary outflow is through evapotranspiration, the wetland will be a sink for sediment and nutrients. Wetlands that discharge into groundwater will serve as groundwater recharge areas.

15.D.4.2 Depth of Water in Impounded or Inundated Wetlands

In impounded or inundated wetlands, the depth of water determines the characteristics of the wetlands. Plant species are very sensitive to inundation depths and periods. Both aquatic and non-aquatic animals in wetlands are largely dependent on water depths for habitat.

Depth of water plays a part in both definitional and legal points of view. As indicated in Section 15.G.2, wetlands are defined as having depth of water less than 6.5 ft. In some States, legal land boundaries are based on the definition of the “waters of the State,” which may be dependent on depth of water. Navigable waters, which are usually defined in terms of depth, are considered public or subject to public trust.

The varying depth during alternating wet and dry periods or hydroperiod determines the types of plant life that inhabit a wetland. Forested wetlands, in particular, are very sensitive to depth and hydroperiod. Plant life is also sensitive to periodic flooding, including extremely rare, high-magnitude flooding events. In natural wetlands, the balance due to hydroperiod and depth is achieved over long periods of time but, in created wetlands, this balance may be difficult to duplicate. Current understanding of the impacts of floods, particularly rare, high-magnitude floods on hydroperiod and wetland vegetation, is limited. This is especially true for forested wetlands. Because of this lack of understanding, the long-term success for created wetlands is less certain.

The mechanism that is used to vary depth in a created wetland is topography. Constructed wetlands should have a very gradually sloping bottom or hummock and hollow topography to make sure that the appropriate depths for desired vegetation are achieved.

15.D.4.3 Velocity of Water

The velocity of water in a wetland is defined by the conveyance and the energy grade of the flow through the wetlands. It is dependent on the density of the vegetation in the wetlands and affects the flood-storage capacity of the wetlands. The relative velocity of the water through the wetlands as compared to the velocity into and out of the wetlands controls sediment deposition in the wetlands. Flushing action for nutrients, pollutants and other materials in the wetlands is also controlled by the velocity. Many wetlands exist as impounded areas with no surface flow or exist in soil-saturated conditions with no surface water. Velocity is not a factor in these types of wetlands.

15.D.4.4 Wave Action

Wave action is an issue where the wetlands have large areas of open water or are exposed to large areas of open water. Wave energy affects the bank stability and can be detrimental to plant life that is subject to long-term exposure to waves. Flushing action can also be controlled by waves. Wave height is controlled by the depth, fetch length and wind velocity. For details on wave height, see Chapter 18, Coastal Zone.

15.D.4.5 Areas Subject to Ice

In the northern areas of the country and at higher elevations, the freezing of soil and water in shallower portions of the wetland limit the growth of some plants. Ice can also affect habitat, flood storage and conveyance capacity. Because groundwater infiltration is more likely at the edges of a wetland, freezing affects the groundwater recharge function of the wetlands. Pollution and sediment control functions may also be affected. Areas subject to freezing may be estimated through field surveys or aerial photography during the winter and by estimating water depth.

15.D.4.6 Effects of Variations in Water Sources

The characteristics of the water entering a wetland affect the nature of the wetland. The timing and variations in depth and velocity for floods and drought affect types of plants that can grow in the wetlands. Some plants that can grow in normal flow conditions may not survive long flood inundation. Severe drought conditions may also affect the survivability of plants. In tidal areas, variations in salinity, due to fresh water inflows caused by storms, can destroy plants.

15.D.4.7 Dissolved and Suspended Materials in Water, Turbidity and Temperature

Dissolved and suspended materials in water play an important part in determining the wetland habitat, the food chain and nutrient supplies. Sediment loading will determine the location of wetlands in the long term. Heavy sediment deposits in wetlands may destroy the wetland by raising the grade above the existing watertable and covering plant life. *"Water temperature and turbidity influence vegetation and fauna, affecting habitat values and indirectly affecting flood conveyance, pollution control and other functions."* (Reference *(11)*, page 10).

15.D.4.8 Size, Shape and Depth of Wetlands

The size and shape of natural wetlands are formed by geomorphic forces such as scour or erosion and/or deposition by wind, water or glacier and by uplift or subsidence. These forces largely determine most of the hydrologic functions such as conveyance and storage capacity. The size, shape and contours are not constant. The same erosional and depositional forces that created the wetland continuously modify the shape of the wetlands. The changes are mostly gradual. However, major floods or other catastrophic events can make rapid changes such as major sediment deposition. These impacts are accelerated by human activity in the watershed especially related to land clearing and construction, which may result in increased flood flows and sediment loading.

15.D.4.9 Wetland Vegetation

Wetland vegetation is dependent on hydrology. But it can, in turn, have an impact on hydraulics. The most obvious impact is in the friction roughness factors that control the velocity of flow through the wetlands. The vegetation produces detritus and organic wetland soils that accumulate, gradually increasing the elevation of the wetland. The buildup of organic material can impede groundwater movement into and out of the wetlands by creating a layer of very low permeability. Vegetation contributes to the water outflow through transpiration. It also affects evaporation by shading the water surface and modifying wind patterns.

15.D.4.10 Wetland Soils

Wetland soils are formed, in part, by sediments and dissolved materials carried by the in-flowing water and organic matter from the wetland itself. But the soil, in part, determines the wetland vegetation. Soil characteristics determine erosion rates and affect groundwater flow as indicated above.

15.D.4.11 Wetland Fauna

Animal life is to varying degrees interactive with wetland hydrology. Microorganisms and small organisms break down detritus affecting soil composition. Larger animals such as beavers, muskrats and alligators physically modify the wetland topography by dam building and excavation. Birds and fish consume vegetation and increase turbidity.

15.D.5 GENERAL PRINCIPLES FOR WETLAND DESIGN

In their book, *Wetlands*, Mitsch and Gosselink (Reference *(15)*, Section 15.G.15) give a list of principles of design and construction for wetlands. These are outlined below:

- The wetland system should be designed for minimum maintenance. The hydrology and plant life should be self-controlling and self-sustaining over the long term. The system should be designed so that it utilizes natural energies. The natural energies of floods circulate nutrients throughout the wetlands.

- Design the system to operate successfully within the natural climate and landscape. Floods and droughts should not be feared for they are a part of nature.

- The system should be designed with multiple goals; however, there should be one main objective with several secondary objectives.

- Design the wetland as an ecotone, which is a transition zone between dry land and deep water. A buffer strip may be needed around the wetland, but the wetland itself functions as a buffer between the dry land and the deep-water areas.

- The wetland system should be given time to become established. Short-term success or failure may not reflect the true success of the system.

- The wetland system should be designed for function and not form. If a particular planting fails, but the desired function succeeds, the objectives are met. Plant diseases and invasion by exotic or nuisance species may indicate other stresses and may indicate false expectations and not ecosystem failure.

- Do not over engineer wetland design with regular geometric shapes. The wetlands should reflect natural contours.

15.D.6 WETLAND TYPES FOR DESIGN MODELS

Wetlands fall into five different types based on how they fit the terrain and how the water is supplied. There may be overlaps, but these five types are presented as a framework for design concepts only. In the next section more specific design models are presented:

- *Surface Water Depression* — The surface water depression wetlands are depressions in the ground with a lining of impermeable soils. Normally, they do not intersect the watertable. This type of wetlands will require a sufficient drainage area to develop necessary surface water and precipitation for water supplies.

- *Surface Water Slope* — Surface water slope wetlands are located adjacent to another body of water, a stream, lake or pond. The water supply is furnished by the adjacent water body. The hydroperiod of this type of wetlands is directly related to the rise and fall of the parent water body. Surface water slope wetlands are relatively easy to construct. The effects of wave action and sedimentation should be considered.

- *Groundwater Depression* — The groundwater-depression wetlands are similar to the surface water depression wetlands, except that they do intersect the watertable. They will usually not have an overland outlet. Water supplies from the groundwater table may be sufficient. Dependency on groundwater for water supply should be approached with caution. A sufficient investigation and verification of the reliability of the level of the watertable should be undertaken by a groundwater specialist to verify the adequacy of the supply before dependence is placed on the groundwater supply. The water level will reflect the groundwater table and will rise and fall in a cyclic manner with the watertable.

- *Groundwater Slope* — The groundwater-slope wetlands are constructed along a slope that intersects a permanent or semi-permanent seep or spring. Surface water and precipitation can be a substantial part of the water supply for this type of wetlands. Groundwater-slope wetlands are more likely to have successful construction efforts than groundwater-depression wetlands.

- *Extensive Wetlands on Flat Plains* — Extensive wetlands on flat plains include the sphagnous wetlands in northern Minnesota and the Northwest and the pocosins along the outer Atlantic coast. These wetlands are frequently supplied with water from precipitation and groundwater. It is difficult to construct this type of wetland. However, damaged wetlands of this type may be restored.

15.D.7 MODELS FOR WETLAND CONSTRUCTION

The basic models for wetland construction depend on water supplies from precipitation, surface water, stream flow, lakes, reservoirs and groundwater. In this terminology, “model” refers to the particular method of supplying water to the wetlands. These water sources may be used singly or in combination depending on how the wetlands fit the topography. The outflows will be through two designer-controlled methods, a spillway structure or surface channels, and through two natural control methods, groundwater infiltration and geographically controlled evapotranspiration. Ten models are presented below.

15.D.7.1 Inline Stream Flow Model

There are two ways to construct wetlands using inline stream flow. One is to follow nature’s example and emulate the beaver by constructing a dam or control structure across the stream channel. The other is to excavate an area adjacent to the stream so that it can be periodically flooded by high water and construct an erosion control weir across the stream. Special accommodation may be required for fish passage. The inline method is more appropriate for areas near the headwaters of the stream. It works well for ephemeral streams or for perennial streams that have low flood discharges and low sediment transport. Placing a control structure at the upstream end of a highway culvert is an inexpensive way to construct an inline wetland. However, before any control structure is placed at the upstream end of a culvert, it should be reviewed by a hydraulics engineer to determine if there will be any detrimental effect on the culvert’s hydraulic performance.

The main water source for the inline model is the stream flow. Flow rates can be determined utilizing hydrograph methods or, if the stream has a USGS gage, gage data can be used for the flow data (see Chapter 7, Hydrology). Flow depths can be approximated by Manning’s equation. A more accurate method is to utilize one of the step-backwater models such as WSPRO or HEC-RAS to compute flow profiles. In complex floodplains, it may be necessary to use a two-dimensional model such as FESWMS.

The main usefulness for the inline model is that it can support a wetland where the soils are relatively permeable. In such cases, the wetlands can be a recharge area. The primary disadvantage is that the wetlands may be constructed in a high-energy area of the stream. This will allow for sediment deposition and erosion in the wetlands. Scour problems along ground-level access roads may also be a problem in high-energy areas of a stream or floodplain.

15.D.7.2 Offline Stream Flow Model

An offline stream model works by diverting water from a stream channel during high-flow periods or by the construction of a weir in the channel that can be utilized to divert water during low-flow periods. As indicated above, special accommodations may be required for fish passage. In some cases, frequent flooding such as the annual flood can be utilized to recharge the wetlands. The offline stream flow model is useful when the stream has a high sediment load, is too flashy, or has high steep banks that are not amenable to inline construction techniques.

Discharge data and water profile data should be determined the same way as in the inflow model process. If the stream has large flow fluctuations and no gage data is available, biologic and geomorphic conditions in the area can serve as guides in establishing wetland elevations. The elevation of existing wetlands and natural levees that control the water retention are essential design information. High-water marks are also important indicators.

The water level in the offline wetland model should be controlled by a weir at the outlet of the wetlands or by the elevation and capacity of the outfall channel. It is important to build flexibility in controlling this elevation through an adjustable weir control. This, as discussed later, will allow for corrections or adjustments in the water level in the wetland.

If sediment control is not a functional goal, then one of the most important considerations in the offline model is to have some sediment control upstream from the wetlands. This is particularly true, because the recharge is usually during high-flow events when the stream is carrying a large sediment load. The majority of the sediment should be trapped before it reaches the wetland area. However, some of the finer materials may provide nutrients to the vegetation in the wetlands.

Some of the advantages of the offline model are:

- The stream will furnish an adequate water supply.
- The monetary value of floodplain land is relatively low.
- A minimum of excavation would be needed.
- The model will work with permeable soils.
- The wetland can be a link with other wetland habitats.

The main disadvantage is that there may be difficulties in obtaining permits for the channel modifications.

15.D.7.3 Spring /Seepage Flow Model

Wetlands developed using this model fall into the category of groundwater-slope wetlands. They are constructed just down slope from a spring or from a point where the groundwater table intersects the surface. The wetlands are constructed by excavating a benched area and building a dam to contain the water.

The flow rates from the groundwater source must be known or estimated. Flow rates may be determined by gaging. A V-notch weir may be needed for accurate gaging. The reliability of the source must be determined. This can be determined by examining historical records, by interviews with long-time local residents and by judging changes in vegetation in the area downstream of the seep. The groundwater can be supplemented with surface water from the uphill area.

It is important to determine if activities in the source area of the aquifer will affect the groundwater flow. Activities that may have an impact are:

- urbanization,
- agriculture,
- forestry,
- irrigation, and
- groundwater development.

The dam structure should be constructed utilizing normal dam design principles. It should be relatively low and have 1V:10H side slopes. This extremely flat slope will help protect the dam from damage by burrowing animals.

The advantages with this type of model are that it is relatively easy and inexpensive to construct and that it depends on a relatively reliable water source. The disadvantage is that a water control structure must be constructed that might fail and that a seep habitat will have to be destroyed.

15.D.7.4 Surface Water Model

This model is constructed by diverting surface water flow into an impounded area. Flow rates can be readily computed based on rainfall records and a synthetic hydrograph. The watershed should produce reliable runoff. The impounded area should have impermeable soils or have sufficient water supply to maintain the required water levels. A spillway structure will be required with sufficient capacity to allow the passage of excess water supply so that vegetation will not be damaged by too much water.

There is a growing body of literature on "moist soil management" for waterfowl habitat. Moist soil management relies on moist soil conditions followed by drawdown periods. The soil moisture is then replenished by flooding. USFWS has an introductory manual for these techniques. See Reference *(6)*, Section 15.G.15. Other literature can be furnished by State and Federal game management agencies and Ducks Unlimited.

The main advantage with this method is that it is easily and inexpensively constructed. The main disadvantage is that it cannot be constructed in areas with permeable soils, unless there is sufficient water supply to maintain the required water levels or unless an impermeable liner is used.

15.D.7.5 Groundwater Interception

Wetlands of this type are constructed by excavating into the groundwater table. Where the watertable and its fluctuations are not known, this type of wetland construction has a high rate of failure. Failure can result from prolonged periods when the watertable is below the wetland surface or extended periods when the watertable is too high. In areas where the watertable is predictable, the side slopes may become too dry during periods of drawdown. This is because of the permeable soils that area associated with the watertable strata. The groundwater can be supplemented with surface water runoff.

15.D.7.6 Shared Water Supply

Wetlands, constructed for mitigation purposes, are often placed adjacent to existing wetlands and connected so that they can share the same water supply. If there is not a sufficient water supply, this may lead to failure of the existing and the new wetland. First, the most critical concern is the elevation of the new wetland and the connection channel. The new wetland must be at an elevation similar to the original wetland. If it is higher, it may be too dry to support wetland conditions. If it is too low, it may drain the original wetland causing it to fail. There must be an assurance that the water supply is sufficient to support both wetlands. The soil permeability of the new wetlands and the connecting channel must be thoroughly investigated. If the soils are permeable, the resulting infiltration may drain the existing wetlands causing both wetlands to fail. The use of barrier membranes buried 1 ft to 2 ft below the ground surface to create a perched watertable can be an option.

15.D.7.7 Aquatic Bed

Aquatic bed wetlands are zones of leafy vegetation that grow floating or suspended in the water column. To construct an aquatic bed wetland, utilize an existing water body or construct one that has an adequate water supply. One of the most important considerations is that aquatic bed plants are very sensitive to water energy. They cannot withstand velocity or wave action without suffering physical damage. The best guide is to plant vegetation that grows in similar areas near by. Construction of aquatic bed wetlands may have to be done on a trial basis to be assured that the low energy requirements of the plants are met.

15.D.7.8 Lakeshore

Lakeshore wetlands are constructed as fringe areas between the lake and dry land. There are several concerns that must be addressed. First is protection for the wetland area from wave energy. This will be dependent on fetch length and the amount and type of boat traffic on the lake. It may be necessary to construct a breakwater to protect the area. During early establishment, the wetland area may have to be protected from human and animal intrusions and damage. A barrier with fencing can be constructed to protect the wetland area. Varying water levels in the lake are an important design consideration. The appropriate hydroperiod must be maintained in the wetland area to support the wetland vegetation. Reservoirs that are used for power generation will have drastic changes in water level that may prohibit conditions favorable for wetland development.

15.D.7.9 Island Wetlands

USACE has had success in developing wetlands on dredge disposal islands. The main concerns are protection from wave action and currents and construction costs.

15.D.7.10 Riparian Rehabilitation

"In the western United States, much concern has focused on protecting and reestablishing riparian habitats on degraded streams. It is important to note that such riparian areas are not jurisdictional wetlands and are not covered by Section 404 of the Clean Water Act. Nevertheless, such restorations can be incorporated into mitigation efforts as DOT's partner with their sister agencies. Such restoration can enhance existing wetlands increasing their functional values and thereby be a significant contribution to a mitigation effort. Most problems with riparian degradation have to do with land use practices, especially grazing and agricultural practices. Methods used to deal with these problems are currently being developed and some are provided in Jensen and Platts." See Reference *(16)*, Section 15.G.15. This area of concern is beyond the scope of this *Manual*.

15.D.8 TIDAL WETLANDS

Restoration or creation of tidal wetlands presents some unique problems and requirements because of tidal and wave effects and problems associated with salinity tolerances of vegetation. These are presented below.

15.D.8.1 Fresh Water Flooding

Flooding from fresh water streams causes some serious problems for coastal wetlands. Large floods can drastically alter coastal wetlands due to sediment deposition and by diluting the salt water, drastically changing the salinity of the water. Problems associated with sediment deposition from floods are particularly marked along the Pacific Coast where coastal wetlands are relatively small. One Southern California lagoon, Mugu Lagoon, had a 40% reduction in the low-tide volume due to a flood in the 1980s. In addition, floods can wipe out fish and invertebrate populations, some of which have a very low tolerance for variation in salinity.

15.D.8.2 Seasonal Pulses of Fresh Water

Along the Southern Pacific Coast, the seasonal pulses of fresh water are very important to wetland species. Most coastal halophytes are tolerant to high salinity but have low germination and seedling survival rates in saline conditions. They depend on the fresh water pulses for germination and early growth. In contrast, frequent flooding can allow fresh water species to invade the coastal wetlands, thus crowding out saltwater species. Restoration of saltwater wetlands is especially difficult where dams have been built upstream, controlling the inflow of fresh water into the coastal wetland.

15.D.8.3 Sedimentation and Erosion

A moderate amount of sedimentation from tidal and wave action has a positive effect by bringing in nutrients to the wetland. Excessive sedimentation can choke out vegetation and be detrimental to aquatic life. Erosion by currents or wave action can destroy vegetation. Blowing sand can be a problem. Wind breaks or fences may be needed to protect plants from blowing sand. Dredged materials or sediment from industrial areas may bring in contaminants.

15.D.8.4 Depth

A number of coastal wetland plants have a narrow range of water depth tolerance. This means that the determination of tidal elevations and wetland elevations are critical in the design of coastal wetland projects. The slope or topography of the tidal wetlands will determine the extent of the wetland vegetation.

15.D.8.5 Salinity

The salinity must be in the tolerance range for the vegetation and aquatic life. Precipitation, fresh water runoff and fresh water seepage affect the salinity and bring in nutrients. This causes increased growth in salt marsh vegetation and affects species composition and diversity.

15.D.8.6 Soils

Soils should be a consideration in tidal wetland restoration projects. Mechanical work such as grading is easier in sandy soils. However, silts and clays will generally have more nutrients. Fertilizers may be needed in sandy soils to promote vegetation. The fertilizer should be the slow-release type. Acidic soils may need the application of lime. Organic matter should also be added.

15.D.8.7 Hydrologic Conditions

Hydrologic conditions affect many chemical and physical processes including nutrient cycling, organic matter accumulation and import and export of organic matter and mineral nutrients. The water in the upstream ends of tidal creeks and marshes may not be circulated out of the area by tidal action but simply flushed back and forth.

15.D.8.8 Channel Networks

In the restoration or creation of coastal marshes, it may be necessary to construct a network of interconnected channels similar to the natural channel networks that are typical for natural marshes of this type. To accomplish this, a survey of adjacent marshlands will serve as a guide for the extent of channels needed. The constructed channels should duplicate the irregularity and sinuosity of the natural channels. The channel network will greatly enhance wildlife habitat values and will facilitate healthy vegetative growth in the marsh.

15.D.8.9 Sea Grasses

For sea grasses, flow conditions are important. Waves and currents that stir up the sediments cause turbidity and interfere with the quantity of light reaching the plants. Even 0.04 in to 0.08 in of degradation per day will cause a 50% failure rate of the plants. Site hydrology affects the form of the beds. In high-current areas, patchy growth takes place although, in quiescent areas, relatively continuous meadows develop. In developing sea grass plantings, upland sediment should be trapped before it reaches the planting area. Offshore berms or dunes can be used to act as a buffer from wave action, although this is not well thought of by many scientists.

15.D.9 SUCCESS RATES IN WETLAND RESTORATION/CREATION

There has been a relatively high success rate with restoration of fresh and saltwater marshes. One exception is saltwater marshes with Spartina patens, which has very sensitive elevation requirements. Spartina patens is a type of cord grass that grows in the upper tidal area, usually only the area affected by spring tides. Much less success has been achieved with seagrasses and forested wetlands. Why the seagrasses fail is not clear, but success seems to improve if the grasses are planted at a site where they have grown previously. The forested wetlands have sensitivity to long-term hydrologic conditions. Also, this type of wetland takes a long time to mature.

"The success of a project depends upon the ease with which the hydrology can be determined and established, the availability of appropriate seeds and plant stocks, the rate of growth of species, the water level manipulation potential built into the project and other factors. To date, the least success has been achieved for wetlands for which it is very difficult to restore or create the proper hydrology." (Reference *(13)*). The ease by which different project types can be constructed successfully are given below in order of probability of success:

- Estuarine marshes are the easiest and most successful wetlands to develop because of:
    - the ease of determining and establishing the hydrology,
    - the amount of experience and literature available on the subject,
    - the small number of plant species involved,
    - the availability of seeds and plant stocks, and
    - the ease with establishing many of the plant species.

  (There are exceptions, including Spartina patens previously mentioned and hypersaline soils common in Southern California.)

- Projects in coastal marshes are almost as successful as estuarine marshes for the same reasons. However, high wave energies and tide ranges can reduce the chances for success.

- The next highest success rate is for marshes along lakes, rivers and streams. In these types of wetlands, the hydrology data is often available through USGS gage record data. There is a fair amount of experience and literature available. However, hydrology is more difficult to determine, and the required hydrology is more difficult to create. These kinds of wetlands have a large number of plant species that must be accommodated. Sediment deposition and erosion reduce the success with this type of wetlands.

- Marshes supplied largely by surface water have the next highest success rate. There is less experience and literature available in this area. The hydrology is more difficult to determine and design. Adjustable outlet works will help in the success rate. Vegetation can be complex.

- Forested wetlands are more difficult to restore/create and have a lower success rate. The main difficulty is the determination and design for the hydrology because of the narrow tolerance levels for flooding duration and depth. All of the hydrologic requirements are probably not understood because of lack of knowledge of the long-term relationships between the vegetation and the hydrology. Records of stream flow for adjacent streams can be used but they may not be sensitive enough. There is limited experience and literature available on forested wetlands. Forested wetlands have a wide variety of vegetation with many differing and competing growth requirements. Both the upper-story and lower-story plants must be successfully grown. The time to reach a mature growth in a forest is usually in the order of decades.

- Isolated marshes and forested wetlands supplied by groundwater have the lowest success rate. The groundwater supplies are very difficult to evaluate and are very unreliable in some areas. The experience and literature on this type of wetlands is limited.

Long-term success of a project depends on monitoring, managing and protection of the wetlands. Long-term success can also be affected by land-use changes in the surrounding area, which will usually be outside project control. Projects should be designed as self-sustaining, unless some agency is willing to take the responsibility for long-term maintenance. However, the ultimate end of all projects is that they will be self-sustaining. Common management tools needed are:

- mid-course corrections including replanting, re-grading and adjustments to water level;

- establish barriers, buffers and sediment traps to protect the wetlands from excessive sediment, nutrients, pesticides and other impacts from adjacent lands that can include agricultural activities and urbanization;

- establish barriers and fences to protect the wetlands from foot traffic, off-road vehicular traffic and livestock;

- control invading undesirable plant life by burning, herbicides or mechanical removal;

- remove accumulated sediment by dredging or other means; and

- supplemental watering during early establishment period.

To achieve a greater success rate in wetland rehabilitation/creation, more research is needed in the subject of water depth and duration needs of various wetland animals and plants. More research needs to be done on hydroperiod and the effects of major low-frequency flood events and long-term fluctuations in water levels.

15.D.10 FAILURE MECHANISMS FOR WETLAND RESTORATION/CREATION PROJECTS

Hollands (Reference *(8)*, Section 15.G.15) developed a partial list of reasons wetlands restoration/creation projects fail. This list should be used as a check-off list against a potential failure of a project. The reasons are given below:

- goals not properly identified;
- lack of information on lost wetland;
- geohydrology not correctly created (e.g., no low-permeability layer created or one that leaks or a watertable that is not understood properly and is too deep or too shallow);
- water budget not understood (e.g., too little or too much water);
- improper soils;
- improper water chemistry (e.g., saline);
- improper planting (e.g., wrong plant species or density);
- improper maintenance;
- nuisance animals (e.g., geese);
- not constructed as designed, lack of inspection;
- no effective monitoring;
- no enforcement by government agencies;
- lack of funds, economics;
- no method to evaluate degree to which goals have been achieved; and
- no long-term management plan and funds to maintain the system once success has been achieved (e.g., no unconditional guarantee) and failure to identify and address “limiting factors.”

There are additional reasons for failure not listed by Hollands including the presence of invasive species (e.g., purple loosestrife and reed canary grass).

15.D.11 WETLAND RESTORATION/CREATION PROJECT DEVELOPMENT TEAM

The development of a wetland restoration/creation project should be accomplished by a multi-disciplined team. Representatives of the disciplines that may be on the team are:

- ecologist,
- botanist,
- zoologist or wildlife biologist,
- environmental scientist,
- wetland specialist,
- both surface water and groundwater hydrologist,
- hydraulics engineer,
- geologist,
- geotechnical engineers,
- hydrogeologist,
- civil engineer,
- landscape architect, and
- forester.

The project manager should be familiar with all phases of the wetland project development. The project manager is responsible for schedules, budgets, coordination and resource management. It is the responsibility of each of the specialists to report the concerns of their respective areas to the project manager.

Although the manager may not be a hydrologist or wetland specialist, the manager needs to have an understanding of how the maximum, minimum and mean flow conditions affect wetland characteristics and functions. The manager needs to understand the sensitivity of wetlands to changes in hydrology and the impacts such changes will have in the short term and long term. Because the manager may not be familiar with hydrologic and hydraulic terminology, it is the responsibility of the hydraulics engineer or hydrologist to make sure that the manager understands the various hydrologic conditions that will occur.

15.D.12 WETLAND RESTORATION/CREATION PROJECT DEVELOPMENT PROCESS

The wetland restoration/creation project development should follow a logical process. The Steps in this process are:

- Assess the wetland to be replaced or mitigated to determine the functions and values to be replaced. The assessment should include an inventory of the flora and fauna and an evaluation of the hydrology of the wetland site.

- Based on the assessment, establish a baseline of wetland characteristics from which a set of objectives for the proposed restoration/creation project should be developed.

- Establish goals and success criteria for the proposed project based on the objectives and the site analysis.

- Evaluate potential project sites.

- Select project site.
- Depending on the size and complexity of the mitigation required, a detailed evaluation of the project site will include a topographical survey, geotechnical survey, hydrologic evaluation, plant survey and fish and wildlife evaluation.
- Design the project to include the hydraulic design with the development of a water budget, geotechnical design, design for restoration of wetland plants and wildlife, habitat features, a construction sequencing plan and maintenance.
- Construction of the project should include quality control and in-course corrections.
- Monitoring and adjustments.

15.D.12.1 Evaluation of Existing Wetlands

The first five Steps in the wetland restoration/creation process are interrelated and constitute the planning process for the project. One of the more important steps in a successful restoration process is to first identify a reference wetland. The identification and evaluation of a reference wetland is to establish a baseline by which the project mitigation site can be measured. It allows an understanding of the character of the wetland and of its functional values. The success of the restoration/creation project is measured by comparing the finished mitigation site with the reference wetland. An important part of the evaluation is to answer the questions:

- *"Is the wetland being created to replace habitat? What type? Is a similar habitat feasible? What species (plant and animal) are desired?*
- *Is the wetland expected to perform specific functions, such as flood control, wastewater treatment and sediment trapping? What features are required to perform these functions (area, flow rate, etc.)?"* (Reference *(17)*, page 328).

The non-biological areas that need to be evaluated are the topography, the hydrology and the geology. The evaluation of the general topography of the wetlands should include the size and shape of the wetland and the detailed ground contours of the wetland area. The hydrology should include developing and understanding both the groundwater and surface water hydrology of the wetland. In the groundwater investigation, the following areas should be investigated:

- the geologic history of the site including development of an understanding of the existing topographic and hydrologic setting;
- an investigation of the different strata that underlies the wetland site, including a determination of their characteristics such as permeability; and
- the groundwater table using watertable observation wells.

The surface water hydrology evaluation should include the source or supply of water, the types of outflow mechanisms and the quality of the water supply. The interaction of the site hydrology with the surrounding area should be determined. Does the wetland serve as a flood storage area and does it act as a sediment trap? A water budget should be developed, including the groundwater and the surface water.

The drainage area of the watershed and the nature of the watershed should be identified. The land use of the surrounding area should be determined. An evaluation of the interactions between the wetlands and the surrounding area should be made to develop an understanding of the interrelationships that exist and what role they play in the functions of the wetland.

The biological element of the wetlands should be evaluated. Depending on size and location of the wetlands, inventories or counts of the plant and animal life may be taken. Threatened or endangered species must be identified. The functions of the wetlands should be identified and quantified. Because wetlands are not independent of their surroundings, the interaction of the wetland with the surrounding area should be investigated.

One of the most important decisions that must be made for all evaluations in the project development process is the level of detail needed. Should the investigation be quantitative rather than qualitative? Many USACE Districts are now considering a descriptive approach to wetlands functional assessment instead of empirical. The best guide for this decision is the past history of restoration/creation experience in the particular type of restoration/creation being attempted.

If there has been much success in a particular approach to wetland restoration, the level of evaluation is relatively low and qualitative evaluations will probably suffice. If there has been little success or there is little known about the type of procedure to be attempted, then the evaluation should be quantitative and have much greater detail.

Time may be a factor in the amount of detail that is included in the evaluations. Because of project restraints, the investigator may not have sufficient time to observe the wetland under a number of complete wet-dry cycles. The size of the wetland and the number of different habitats will limit the detail of the evaluation. The objective of the restoration/creation project will, to some degree, place constraints on the evaluation. Cost-effectiveness and funding for the project is the final constraint. The importance of each phase of the project development process must be weighed to determine how to optimize the use of the available funds.

15.D.12.2 Establish Goals and Success Criteria

One of the most important steps in the wetland restoration/creation process is to establish the goals and objectives for the project. Without specific and realistic goals and objectives, there is no way to evaluate the success of the project. The goals should be based on the evaluation of the wetland that is being replaced. The design goals are project specific and should be developed by the project team based on the needs of the desired functions of the wetland. All members of the wetland project development team should have input into this process. Considerations for the goals and design criteria should include hydrology, topography, geology, choice of plant species and water control devices. This means that the goal selection, design criteria and the design require a holistic approach, considering all these factors.

In the goal-setting process, it is important to understand that only a few of the natural functions of a wetland can be created. It can take nature thousands of years to develop all of the intricate interrelationships that occur in natural wetlands. The goals must include realistic expectations. It is also important to realize that short-term success (over one year) does not guarantee long-term success. Hydrologic fluctuations such as drought and flood occur on a long-term scale. These may be stressful to some wetland species causing stunted growth and even death. Natural wetlands have achieved a balance with these conditions. Created wetlands may not have the subtle relationships in terms of inundation time and drought resistance that will result in long-term survivability. Wave action and high-velocity flow may cause damage through sediment deposition and erosion to restored/created wetlands. Wetlands in urbanized watersheds often have high rates of erosion and sedimentation. Until they mature, restored or created wetlands may lack the erosional equilibrium of natural wetlands.

Long-term survivability may be affected by non-hydrologic factors. Common threats to wetland survivability include pollution, off-road vehicles, vandalism and animal predation. With this understanding, realistic achievable goals can be set.

15.D.12.2.1 Success Criteria

As part of the goal setting process, specific success criteria matched to functions should be defined. Without specific success criteria, there is no method to determine whether the constructed wetlands are successful. The success criteria should spell out specific plant survival, growth rates and habitat conversion (e.g., open-water impoundment converting to intertidal marsh) based on a realistic time scale. The goals allow the process to be measured and experience to be gained. The success criteria also give a basis for making midcourse corrections. The whole process should be measured against the baseline established in the evaluation of the original wetland. The success depends on how well the original evaluation was done and the practicality of the original goals.

15.D.12.2.2 Timetable for Monitoring

One of the key parts of the goal setting process is to set up a timetable for monitoring the project. The timetable should determine when the project will meet various stages of development and when it should successfully meet the goals. Enough flexibility should be designed into the hydraulic controls for the wetlands so that needed adjustments in water depth can be made if the vegetation is not developing as it should. Other adjustments will be biological in nature, such as removal of nuisance species or replanting. Monitoring should begin when the planting has been accomplished. It should continue until the permit requirements of the regulatory agencies have been met.

15.D.12.2.3 Hydrology Goals and Criteria

The primary goal should be to establish the long-term hydrologic conditions that will support the desired plant community. The hydrology should be designed as a stand-alone system, requiring little or no maintenance once it has become established. Other very important functional goals may be stormwater retention, water quality improvement, sediment control, wastewater treatment, creating fish and wildlife habitat and recreational use. Flood routing analysis is essential in assessing the significance of flood storage benefits of wetlands. Many wetlands do not provide significant flood storage benefits.

Wetland vegetation and wildlife have specific requirements for hydrology to survive and flourish. These requirements are generally for depth and seasonal timing of inundation. Velocity and circulation requirements may be needed to enhance nutrient cycling. The biologist must define these requirements for the hydrologist based on the needs of the specific species of plants and animals that are identified in the goals for the wetlands. These requirements are the hydrologic goals for the wetland project. Once the goals have been furnished, the next step for the hydrologist is to define the hydrologic design criteria needed to achieve the project goals. The hydrologic design criteria should provide for some control flexibility so that adjustments in water level can be made. This is because hydrologic needs for vegetation are not completely understood and hydrology for a watershed cannot be determined to a sufficient level of accuracy to fully realize these goals.

15.D.12.3 Selection of Project Site

The site selection process is probably the most difficult part of the restoration/creation process. It involves finding a site that will meet the goals of the project that will satisfy the requirements of the regulatory agencies. The most important criterion for site selection is that the required hydrology can be established. Soils and geology characteristics are critical factors in determining whether this can be accomplished. Other questions that must be addressed are:

- Will the site be large enough to meet the mitigation requirements?
- Is there sufficient room for a buffer strip to protect wildlife?
- Can the property be acquired?
- Is the cost within the project budget?
- Can the site be protected from detrimental human intrusion?
- Is there a landowner who is willing to sell a potential site?
- Is the replacement wetland site in close proximity to, within the same drainage basin, or greatly removed from the disturbed wetland?
- Are there water rights considerations?
- Will the site create health or safety hazards to the public?

These are among the many questions that must be addressed before the final site selection can be made.

Potential sites should be identified in the project area. Preferred sites should be wetlands that have been destroyed or damaged. Creation of wetlands is a last resort option according to most resource agencies. Although the preferred sites are previous wetlands or damaged wetlands, areas where topography is advantageous may present a better choice. All sites should be evaluated using the process described previously. The evaluation process should become more and more detailed as the site selection process is narrowed down. The hydrologic investigations need to be in sufficient detail to determine whether the proposed site will meet the goals for the project but not necessarily to the detail required for design.

The first consideration is to determine if the site has sufficient area to meet the project goals. Associated with this question is the hydrology. Is the water supply sufficient in quantity and quality to support the wetlands? If the site has been a wetland, the size of the project should not be larger than the original wetlands unless there is an additional water supply. The drainage basin size and land use, both present and future, should be determined. If sediment is a problem, there should be sufficient area for a sediment trap (see *MDM* Chapter 16). Buffer strips and vegetated upland areas around wetlands are often critical for the success of a project. If wildlife habitat is one of the goals, there is an additional need for a fenced buffer strip to protect the wildlife from human and livestock intrusion.

Would the activities of the surrounding area be detrimental to the wetlands? It is important to have some assurance that the land uses will not change. It would be detrimental to the restored wetlands if land use changed, affecting the water quality or quantity or endangering the wetlands through some other mechanism. If land in the drainage area supporting the proposed/restored wetland changes from vegetative cover to impervious area, the wetland would have more water than it was designed for.

Land use of the site, both past and present, is important to the success of the project. If the site had been wetlands, it is important to determine what caused the damage to the wetlands. Can the hydrology be reestablished? Can the damage be repaired?

If flood storage is an important functional value, then one of the more important considerations is where the site is located relative to the watershed. Sites near the headwaters of a watershed will provide for better flood storage effects and also have less sediment inflow problems. The wetlands will be less affected by flood peaks as well. Adequate storage area must be available. The effects of flood flows on vegetation need to be evaluated. Flood routing analysis of the watersheds is essential to account for timing of peak flows from the wetland and the watershed's subbasins. The location of a restored or created wetland in the lower portion of a basin may be subjected to more stress from floods than if it is located further upstream. A wetland may provide for local flood reduction but, in some unusual cases, may change the peak timing resulting in an increase in downstream flooding on the main stream. For this reason, a flood routing analysis is needed to determine if this condition may occur.

The availability of seed stocks is an important consideration. If the site has been a wetland, there may be dormant seeds or other propagules (such as rhizomes) available in the soil. When the appropriate conditions are created, the seeds will germinate and the vegetation will be well on the way to reestablishment. One of the best sources of seed stocks is to salvage the muck from wetland sites to be disturbed by the project and to place the material at the replacement wetland site. Seed stocks may also be available at nearby wetlands; however, care should be exercised that invasive seed or rootstocks are not present. Stockpiling of these materials may cause adverse changes in soil chemistry.

The relationship between hydroperiod and substrata should also be evaluated. Wetlands require a layer of soil with low permeability to contain the water, a high watertable or sufficient water supply to provide the necessary watertable in pervious soils. Substrata can be modified, although with some difficulty, but hydroperiod may be difficult to establish.

If one of the goals of the project is wastewater treatment and/or sediment control, estimates of the quantities and types of materials should be made. Adequate volumes of storage and treatment space will be needed.

One of the most important considerations is the cost of developing the site. This would include cost of the land, construction cost, including the proximity of borrow and disposal sites, and long-term maintenance costs. Where the land costs are too high, the costs of wetland construction can sometimes be reduced through the use of a large wetland bank. Wetland banks can also be used when there are no appropriate mitigation sites available in the vicinity of the project site.

Right-of-way is also an important consideration in the selection of a mitigation site. When wetlands are encountered on a highway project, the law requires that the priority of dealing with this issue is first avoidance, then minimization of impacts, mitigation at or near the project site, mitigation in the same watershed and, finally, off-site mitigation to include the possible use of a bank. If the mitigation site is contiguous to the highway construction project, the right-of-way will be part of the project right-of-way and included in the normal project permitting procedures. Included in these procedures would be the need for public input and consideration of environmental and social impacts. For off-site locations, the right-of-way would be purchased either as a fee simple purchase or as a permanent easement. The easement would allow the property owner to have access to the property for hunting, fishing, etc., but would not allow any development of the site other than the wetland development. Any construction in wetlands would require the appropriate permits.

15.D.12.4 Detailed Evaluation of Proposed Site

Once the site is selected, a detailed site evaluation should be conducted. This evaluation should be much like the initial site inspection but more detailed. An accurate topographic survey should be made. The accuracy of the survey should be controlled by the water depth tolerance of the proposed vegetation for the wetlands. Other items needed are aerial photography, preferably color infrared, planning maps, soils maps and land-use maps for the watershed. The color infrared photography will be useful in determining the extent of different types of vegetation.

A detailed groundwater investigation should be made. Soil test borings should be performed to determine the strata in the proposed wetland area. Soil permeability should be determined for each stratum encountered. If groundwater is one of the sources of water for the wetlands, the watertable needs to be defined and its seasonal fluctuations must be determined. If possible, the long-term variations in the watertable should be identified. This phase of the investigation may require the services of a groundwater specialist.

The basic hydrology for the site should be determined. This determination will of course depend on the location, topography and type of hydrology that occurs at the site. The data should include drainage area, land use, soil type, hydrologic parameters, time of concentration and rainfall data. The rainfall data should include an annual summary covering the length of record of the nearest long-term rain gage. From the records, select the wettest year of record, the driest year and a year of average rainfall. For each of these years, obtain daily rainfall records. This data will be used to develop a water budget for the wetlands.

For sites along streams, gage data should be analyzed if there are gages on the stream. If possible, a complete hydrograph of daily stream data for the wettest year of record, for the driest year and for an average precipitation year should be generated for the stream at the site location. This hydrograph will be the basis for the water budget developed for the proposed wetland. For ungaged streams, both high- and low-flow frequency discharge data should be computed using appropriate methods from Chapter 5.

For tidal sites, existing tide gages need to be identified. If there are or have been gages located near the site, the tide data should be obtained. The National Oceanic and Atmospheric Administration (NOAA) has gage descriptions and benchmark data listed on the Internet. Reference stations are gages where long-term data has been collected. These stations are published in the Annual Tide Tables that have been published by NOAA. NOAA is no longer publishing the Tide Tables but has turned this over to private publishing companies. Full gage records are available through NOAA's record library. If there are no tide gages near the site, a recording gage should be placed and maintained for at least 30 days. This gage and the recorded readings should be correlated to a reference station so that the 19-yr tidal cycle can be synthesized.

The biological evaluation of the site should include inventories of all plant and animal life. Special note should be taken of nuisance species that might overwhelm native wetland species and disrupt the proposed wetland species.

15.D.12.5 Design Process for the Wetlands

The design process for the hydrologist involves (a) determining the adequacy of the water supply to meet the requirements for the proposed wetland vegetation by developing a water budget for the wetlands, (b) designing water quality structures to remove sediment and other contaminants from the water before it enters the wetlands if necessary, and (c) designing the outlet control and outlet channel. The hydrologist must also be involved in the construction plan preparation process and in establishing the construction sequence and time schedule. All of this design work must be accomplished in close cooperation with the wetland specialist.

15.D.12.5.1 Water Budget

The water budget is a routing process that accounts for the elements that affect the water level in the wetland. These elements include water inflow, outflow and storage in the wetlands. Detailed design procedures for the water budget are given in Chapter 7, Appendix 7.D.

The water budget can be constructed in two ways. One is to provide several times the needed water. The detail and accuracy of the budget for this approach is relatively imprecise. The other approach involves determining the actual water needs. Of necessity, this approach requires a much more detailed analysis and entails a higher risk of failure due to the following reasons:

- the calculation of inputs and outputs is imprecise;
- the calculations represent an approximation of the true climatic cycle and may not be representative of normal conditions;
- non-representative events may have been used as the basis for the computations;
- imprecise estimates were used; and
- no allowance was made for adjustments to outlet structures.

15.D.12.5.2 Specific Features of Design

There are a number of structural and functional features that must be considered in the design of the wetlands. These are the shape, size and contours of the wetlands, treatment of the inflow water and buffer strips, channel design, outlet control structure and the outfall channel.

15.D.12.5.2.1 Shape, Size and Contours of the Wetlands

The shape of the wetlands should reflect the general topography of the area in which it is located. Natural shapes are more aesthetically pleasing and should be used as a model. Standard geometric shapes should be avoided. The size of the wetlands is dictated by the established goals and by the water supply capacity of the watershed. Contouring of the wetland bottom should be gradual or irregular. A very gradually sloped bottom will enhance the depth and drawdown requirements of the vegetation. The plans accuracy for the contours should reflect project needs and construction limitations. If necessary, a contour accuracy of 25 mm can be generated, but mapping costs should be carefully considered.

15.D.12.5.2.2 Protection of the Wetlands by Treatment of Inflow and Buffer Strips

Water quality is one of the concerns in wetland design. The quality of the water supply must be compatible with the proposed vegetation. In watersheds that include urban or industrial development, agricultural lands and high-energy streams, surface waters may need treatment to remove sediment and pollutants. Most wetland plants are very effective at pollutant removal, so a pretreatment wetland may be needed to purify the water before it enters the main project area. Good access to the sediment ponds or traps will be needed for the removal of excessive sediments. Where sediment ponds are expected to be permanent features of the wetlands, a maintenance schedule will have to be developed to remove the accumulated sediments from the sediment trap. Sufficient funding will have to be available to finance the maintenance. Where overland flow from agricultural land or other disturbed land flows into the wetland area, a vegetated buffer strip may be needed to remove sediment and pollutants.

15.D.12.5.2.3 Channel Design

If stream channels are to be constructed as part of the wetland project, they should be relatively wide and shallow with a parabolic cross section to reduce water velocities. Slopes should be as flat as possible to reduce the erosion potential. Flow deflectors should be placed approximately every 100 ft to force meandering. If at all possible, slope changes should be avoided. If a slope change cannot be avoided, stable channel design procedures given in Chapter 8, Channels, should be used to prevent erosion.

15.D.12.5.2.4 Outlet Control Structure and Outfall Channel

One of the most important components of a wetland project that is based on the impoundment of water is the outlet control structure. It is the feature that controls the water level in the wetland. It will usually consist of a berm, dike or a dam. Any dam structure should be constructed in compliance with appropriate dam safety regulations. The structure should be constructed as a low-maintenance structure. To prevent problems due to burrowing by rodents, it should have 1V:10H sloped sides with a broad top. Wetland control structures are usually low-head structures from 1 ft to 2 ft high. If greater water depths are needed in the wetlands, the area may be excavated upstream from the dam with a shallow berm separating the deeper area from the dam. This will reduce the head on the dam and reduce the potential for leakage. This type of design has a number of important features:

- large quantities of soil can be placed in the dam even though it is low;
- the need for a core is reduced;
- the danger of a piping failure along tree roots is reduced;
- the wide top can be used for vehicular or pedestrian traffic;
- muskrat and nutria burrows, which often cause failure in steeper banks, will not breach the wide structure;
- burrowing animals will seek steeper banks for den sites, if available;
- the flat slopes will provide a gradual depth change, maximizing drawdown and increasing plant diversity and vigor; and

- the dike top can be used to increase upland habitat diversity.

A spillway should provide the actual water depth control. This structure should be constructed with removable flashboards or other adjustable controls. The control elevation should be adjustable to the order of 1 in. The spillway should be designed to handle the 100-yr flood. Because of the broad width required, the spillway may need to be designed as a weir or a contracted channel. The weir flow equation is:

$$Q = Clh^{1.5}$$

where:
- Q = discharge, ft^3/s
- l = effective length, ft
- h = head, ft
- C = the weir coefficient

Contracted flow should be computed utilizing standard step-backwater procedures. Computer programs such as WSPRO and HEC-RAS can be used for this procedure.

The outfall channel should be designed to prevent erosion, utilizing riprap or other erosion control measures. Channel design is described in Section 15.G.12.5.2.3.

15.D.13 CONSTRUCTION CONSIDERATIONS

Adequate planning and design can be nullified by improper construction techniques that are not compatible with the goals of the project. A good set of plans and specifications is required. There are many ways to educate the contractor on the sensitive nature of the project. Two of the more important ways are:

- make the contractor aware of design specifications and logistics through one or more preconstruction meetings; and

- provide on-site supervision by a qualified wetland specialist, preferably the one who designed the system.

Highly disturbed areas such as dikes, channels, berms and other control areas should be designed and constructed so that, in a few years, they can be removed or otherwise obscured from the scene. Permanent fixtures should be constructed to blend with the area.

Soil stabilization is essential for newly prepared sites to prevent soil erosion and to prevent the formation of gullies. This can be achieved though cover planting and contouring. Contouring must be accomplished with careful attention to elevation and the watertable. Contours should be as gentle as practical.

During construction, areas may need to be de-watered, or the watertable may need to be lowered. Restoration of such wetlands may need a dam or water control structure. Methods of de-watering include pumps, ditches and drawdown wells. Consideration must be given for the effects of the water on downstream areas. Sediment and erosion control must be among the considerations.

For many situations, it may be desirable to supply additional water during the establishment period. This may be especially true in highly permeable soils. The source for the water may be trucking, which can be very expensive. In the more arid regions of the nation, water rights will have to be acquired to secure the additional water.

Timing of construction is critical. Close coordination with the construction schedule and the seeding or planting schedules should be maintained. The construction should be completed just before the prime planting season so that there is a minimum of exposure time between the earthwork completion and the planting of cover. Erosion and soil stabilization are the primary concerns. It may be necessary to plant a temporary cover crop until the wetland vegetation can be established.

15.D.14 MONITORING

An important aspect of a wetland restoration/creation project is monitoring. This is primarily the responsibility of the wetland specialist. Monitoring serves several important purposes:

- The first is to measure the progress of the vegetation and wildlife establishment in the wetlands.
- The most sensitive time for water depth, hydroperiod and drawdown for vegetation is in the early stages of development. The monitoring should be done to make sure that the water needs of the vegetation are adequately met. Corrections or adjustments in water supply or depth may be required. If such adjustments are apparent, the other team members should also be involved so that future actions can be correlated.
- Monitoring should provide a measurement of how well the original goals of the project are met and provide a learning experience for future projects.
- Replanting may be needed if vegetation is damaged or fails.
- Repairs may be needed if damage from human or animal actions occurs.
- Invading nuisance species may have to be removed by mechanical means or herbicides.

Monitoring should be done on a schedule established during the planning stage of the project. The time frame over which monitoring will have to be done will depend on the type of wetlands being established and is generally established by regulations or regulatory agencies. Forested wetlands, which do not mature for many years, will probably require the longest monitoring period. The services of the hydrologist may be needed if large adjustments are needed in the water supplies. However, the original design should have enough adjustment built into it to handle most required changes.

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